HSR:WHL:MPC
VIII-3

UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON

Letter
Circular
LC-701
(Supersedes LC-493
and LC-343)

(August 29, 1942)

SOLDERS AND SOLDERING

Many requests come to the National Bureau of Standards for information on solders and soldering. This letter circular has been prepared to give essential information on the subject in a condensed form in answer to such inquiries.

I. General considerations

The term "soldering" is generally understood to mean the joining of two metal surfaces by means of another metal or alloy which is applied in the molten condition. The metal which forms the joint is the solder. Pure metals may be used as solders, but practically all solders in common use are alloys.

To form a satisfactory soldered joint it is necessary to heat the metal at the joint at least to a temperature at which the solder is entirely molten. One of the distinctions between a soldered joint and a welded joint is that in the former the metals to be joined are not heated to a temperature high enough to melt them. Consequently, one of the requisites for a solder is that its melting point must be lower than that of the metals being joined. It is generally believed that to obtain satisfactory adhesion of the solder it is necessary that the solder, or one of its constituents, shall form an alloy with the metals which it is to join. On the other hand, it has been claimed that satisfactory adhesion can be obtained without actual alloying of solder and metal. An extremely clean initial surface and its maintenance throughout the soldering operation would be required and such a condition would be extremely hard to meet in practice.

II. Classes of solders

The solders in general use may be divided into the following classes:-

1. Soft solders
2. Hard solders
   a. Silver solders (silver brazing)
   b. Brazing solders
3. Aluminum solders

Recently a number of preparations designated "Liquid Solders" or "Cold Solders" have come into the market. These preparations are recommended by their promoters for the joining of all sorts of materials, non-metallic as well as metallic, without the use of heat. Most of these preparations are really cements or "glues" and are not solders in the generally accepted meaning of the term. Although they may make joints with satisfactory strength for many purposes, they do not form a metal-to-metal bond and cannot be used to make joints to conduct electric current.

III. Necessity for fluxes

The strength of a soldered joint in normal service depends primarily on the adherence of the solder to the metals being joined. To secure good adherence it is necessary that the surface of the metal and of the solder be free of oxide, dirt, etc. The metal is normally covered with a film or layer of oxide and the amount of oxide increases as the metal is heated to the soldering temperature. Hence, to enable the solder to "wet" the metal, it is necessary to employ a covering material which will remove the oxide film already present and also protect the surfaces of both metal and solder from the air while they are being heated to the soldering temperature. A material performing these functions is known as a soldering flux.

IV. Soft solders

(a) Composition and properties

Soft solders have a number of very desirable properties. They have comparatively low melting points and will withstand a considerable amount of bending without fracture. They can be applied by simple means, and can be used for joining metals with relatively low melting points. One of their chief disadvantages is their comparatively low strength.

The metals almost universally used as soft solders are the lead-tin alloys. The eutectic alloy containing 63 percent tin and 37 percent lead melts at about 360°F (182°C). All the other lead-tin alloys, on heating, begin to melt at this temperature but are not completely molten until a higher temperature has been reached. This temperature depends upon the relative amounts of lead and tin in the alloy.

The most widely used "all purpose" soft solder is the "50-50" alloy containing 50 percent lead and 50 percent tin. The temperature at which this alloy is completely molten is variously given as 415°F to 440°F (213°C to 227°C). The alloy containing about 2 parts of lead to 1 part of tin is used in preference to the "half and half" alloy for making "wiped" joints, as it remains partially molten over a wider temperature interval and therefore can be molded during solidification. Most commercial soft solders contain small percentages of antimony which is claimed to increase the strength of the solder. These are other modifications of the lead-tin alloys for soft soldering purposes, the advantages or particular applications of which are not discussed here. The compositions of various commercial lead-tin solders are listed in the table under Specifications.

For the soldering of zinc and galvanized iron and steel, the lead-tin solder used should be free from antimony. The ordinary lead-tin solders can not be used for soldering pewter. The metals known as pewter consist largely of tin or lead, or both, and melt at approximately the same temperature as the lead-tin solders. The following alloys, which have sufficiently low melting points to be applied as solders on pewter, have been recommended for this purpose:-

Designation Number	Composition in Percent		
	Lead	Tin	Bismuth
1	25	25	50
2	50	37.5	12.5
3	25	50	25

An alloy of 95 percent tin with 5 percent antimony, melting at approximately 450°F (232°C) with a small melting range, has been recommended for use as a soft solder. Joints made with this alloy are claimed to have somewhat higher strength than those made with lead-tin solders.

For joints which are required to withstand temperatures close to or slightly above the melting temperature of lead-tin solders, soft soldering with an alloy of 95 percent cadmium with 5 percent silver has been recommended. This alloy begins to melt at approximately 640°F (338°C) and is completely molten at approximately 740°F (393°C).

(b) Lead-base solder

Current restrictions on the industrial uses of tin have been reflected in the limited availability of tin-lead solders since over one-fifth of the metallic tin used enters into the manufacture of solders. Of the various non-strategic metals suitable for solder, lead and silver head the list. Lead-base (tinless) solder as a lead-silver alloy has already proved its usefulness as a substitute for many purposes. A low silver content, approximately 4 percent, is usually recommended. The lead-silver eutectic alloy, containing close to 2.5 percent silver, is very fluid when molten but remains molten over a very short temperature interval, hence the reason for a somewhat higher silver content. The melting range of the lead silver solder is considerably higher than that of the ordinary lead-tin solders, hence the soldering and fluxing techniques are somewhat different. This type of solder has been used with satisfaction on copper and copper-base alloys and on tin plate. As yet, a suitable technique for its use on black steel sheet has not been developed.

(c) Fluxes

The fluxes ordinarily used for soft soldering are solutions or pastes that contain zinc chloride or a mixture of zinc and ammonium chlorides as the active fluxing agent. The solvent or other medium holding the flux material is evaporated by the heat of the soldering operation, and a layer of the solid flux is left on the work. At the soldering temperature the flux melts and partially decomposes with the liberation of hydrochloric acid. It is this acid reaction which enables the flux to dissolve the oxides from the surfaces of the solder and the basis metals. The fused flux also forms a protective film that prevents further oxidation from taking place. Thus, the two-fold function of a flux is fulfilled. It is claimed that a flux containing zinc and ammonium chlorides in their eutectic proportion (71 percent by weight of zinc chloride to 29 percent by weight of ammonium chloride) is the most satisfactory flux for soft soldering.

Because zinc chloride fluxes have a corrosive action, it is sometimes necessary to employ a different flux for certain types of work where the last traces of the flux cannot be removed after the soldering is completed. Rosin is the most commonly used flux of this type. Stearine is also a mild flux for many soft soldering jobs but is corrosive towards lead and lead alloys. Soft solder wire with a core of rosin is obtainable commercially. Palm oil, olive oil, or rosin, or mixtures of these have been recommended as suitable fluxes for soldering pewter.

(d) Application

Soft solders are usually applied with a soldering "iron" (actually made of copper), but may be applied with a flame as the source of heat. Difficulties may arise by using a blow torch if precautions are not taken against overheating. An excessive amount of solder is to be avoided. Except in "wiped" joints the minimum amount of solder that will spread evenly throughout the area of contact between the metals to be joined produces the strongest joints.

(e) Remarks

The best test of a solder is, of course, a practical soldering test. However, very useful information can be obtained by a relatively simple qualitative test consisting in observing the spreading of a drop of the solder on a properly fluxed surface of the basis metal to be soldered while maintained at a temperature somewhat above that at which the solder becomes completely molten. The rate at which the solder drop spreads over the surface and the degree of alloying occurring between solder and basis metal are useful indices of the relative merits of solders. By such a simple test, it is possible to show, for example, the pronounced difference in the behavior of lead-silver solder used on a copper base and on one of black steel.

Because of the comparatively low melting temperatures of the solders, joints soldered with lead-tin solders do not withstand service temperatures higher than about 350°F (177°C); those soldered with the tin-antimony solder would melt apart at about 450°F (232°C); and those soldered with the cadmium-silver solder, at about 640°F (338°C). Investigations at the National Bureau of Standards of the dependability of soldered joints in copper tubing such as is used in domestic plumbing systems established the fact that joints made with tin-base solders are entirely dependable provided the service temperature does not exceed 250°F. Hard solders melt at temperatures above about 1200°F (649°C). There are at present no satisfactory solders with high ductility and strength that melt within the temperature interval, 640°F to 1200°F.

V. Hard solders

There are several types of hard solders, namely precious metal alloy solders and brazing solders. The most widely used precious metal alloy solders are the silver brazing solders, generally alloys of silver, copper, and zinc. Silver brazing solders are malleable and ductile and silver soldered joints in many metals may be as strong as the metals themselves.

Other precious metal alloys used as solders are the gold solders and the platinum solders. Gold solders are used primarily for joining gold and gold alloys. The solders are generally alloys of gold with copper, silver, and zinc, and have lower melting points than the alloys which are joined. Gold solders are generally designated by karat numbers indicating the fineness or karat number of the alloy with which they should be used.

Soldered joints in platinum and platinum metal alloys may be made with fine gold or the higher karat gold alloys. Tungsten can be soldered to copper with a silver solder such as No. 7 (Table 1). (Sodium cyanide has been used successfully as a flux for this.)

Ordinary brazing solders are generally alloys of copper and zinc. They are more brittle than silver brazing solders and do not withstand bending and impact as well as the more ductile solders.

VI. Silver brazing solders

(a) Composition and properties

There are many variations in the proportions of silver, copper and zinc used in commercial silver solders. The following compositions, Table 1, together with their melting points and flow points are given in the Welding Handbook, 1942 edition, American Welding Society. It is believed that a solder satisfactory for most purposes for which silver solder is suitable can be selected from this list. The melting point as given in the table is the temperature at which the solder begins to melt; the flow point, the temperature at which the solder is completely molten.

Table 1 -- Silver brazing alloys

Designating Number	Nominal Composition, %				Melting Point		Flow Point		Color
	Silver	Copper	Zinc		°F	°C	°F	°C	
1 a	10	52	38		1510	821	1600	871	Yellow
2 a	20	45	30	5 cadmium	1430	777	1500	816	"
3	30	38	32		1370	743	1410	766	
4	40	36	24		1330	721	1445	785	
5 a	45	30	25		1250	677	1370	743	Nearly white
6 a	50	34	16		1280	693	1425	774	" "
7	60	25	15		1260	682	1325	719	
8 a	70	20	10		1335	724	1390	754	White
9 e	72	28			1435	780	1435	780	
10 a	80	16	4		1360	738	1460	793	White
11 p	15	80		5 phosphorus	1190	643	1300	704	
12 p	50	15.5	16.5	18 cadmium	1160	627	1175	635	

a - American Society for Testing Materials Specification B 73-29.
e - silver-copper eutectic alloy.
p - proprietary alloys.

A method commonly used in metal-working shops to prepare silver solder for miscellaneous uses is to melt together silver and yellow brass (copper 60 percent, zinc 40 percent) in the proportions of 1 part silver to 2 parts of brass.

Alloy No. 11 is widely used and is claimed to be "self-fluxing" to a great degree. It is recommended for copper and copper alloys but not for steel and iron. A recently developed general-purpose silver solder, suitable also for soldering a wide variety of metals including stainless steels, is No. 12 in Table 1.

(b) Fluxes

For ordinary purposes, borax or mixtures of borax and boric acid (75 to 25 percent borax with 25 to 75 percent boric acid) will meet most requirements as a flux for soldering with silver solders, or gold and platinum solders. A proprietary flux containing fluoride is also useful. The user, however, should avoid breathing the fumes from a flux of this kind. Zinc chloride fluxes used for soft soldering are not satisfactory for hard soldering because they do not remain on the work at the temperatures necessary for hard soldering.

(c) Application

All silver solders melt at temperatures above a red heat and cannot be applied easily with soldering irons. Blow torches of various kinds are often used. Silver solders (and also ordinary brazing solders) are frequently applied by heating the whole object, with the solder inserted as a thin strip or other form, in the joint which is to be made, to the soldering temperature in a suitable furnace.

VII. Brazing solders

(a) Composition and properties

The common brazing solders or brazing "spelters" are really brasses containing more zinc, and consequently with lower melting points, than the commercial brasses or bronzes. Hence, they can be used for joining brass, bronze, and other commercial copper alloys as well as ferrous metals. Joints made with pure copper would be classed as brazed joints although they are often termed "coppered" joints in trade practice.

The commonly used brazing solders contain from 40 to 55 percent copper and 60 to 45 percent zinc, the composition most frequently used being the one containing equal weights of copper and zinc. These are brittle alloys and are ordinarily supplied in granular form. Their flow points are above 1600°F (871°C).

(b) Fluxes

The same fluxes used for silver soldering, described above, are generally used with the brazing solders.

(c) Application

Brazing solders are ordinarily applied by means of a blow torch.

VIII. Aluminum solders

Hundreds of alloys have been developed for use in soldering aluminum and aluminum alloys. Most of the solders that have been found to be satisfactory contain tin and zinc in proportions varying from 50 to 75 percent tin and 50 to 25 percent zinc. The alloy containing 60 percent tin and 40 percent zinc is frequently used and will produce joints possessing satisfactory strength.

The solders may be applied without the use of a flux. Rubbing the surfaces of the aluminum under the melted solder with a wire brush or a sharp object such as an old file cleans its surface so that the solder will "wet" the aluminum. The tin-zinc solders can be applied with a soldering iron.

The chief difficulty with soldered joints on aluminum is that the aluminum adjacent to the joint corrodes when the object is exposed in a moist atmosphere as a result of "galvanic" action between the dissimilar metals - the solder of the joint and the adjacent aluminum. This action can be prevented to a certain extent by covering the joint with a moisture-proof paint or varnish but should not be considered as a practicable remedy for all cases.

Although it is generally considered best practice to join aluminum by welding rather than by soldering, aluminum solders serve a useful purpose in applications where the joints are normally well covered with oil or otherwise protected from the atmosphere.

IX. Additional information on solders and soldering

1. Stainless steels

Materials of this class can be soldered with ordinary lead-tin solder, such as the 50-50 grade, although not so readily as most other metals. Hydrochloric acid as a 1-1 aqueous solution is applied first to the areas to be soldered and after an interval of about 5 minutes, without washing off the acid, zinc chloride flux is applied. The soldering operation is then carried out in the usual manner. Silver brazed joints may also be made. The composition listed as 12, Table 1, has been found especially good for the purpose. The special fluoride flux (Section VI-b) is made for the purpose by the manufacturers of the proprietary soldering alloy mentioned, although good results can be obtained with other fluxing methods.

2. Many variations from the compositions of the different types of solders mentioned in this discussion have been found useful for certain purposes. No attempt has been made to discuss in detail the metallurgical principles and theories involved in the use of solders. For more detailed information on the subject, reference should be made to the original papers or books listed below.

(a) General subject of soldering

"Soldering and Brazing" by Hobart. Book published by D. Van Nostrand Company, 250 Fourth Avenue, New York, New York.

"Metal Worker's Handy Book of Receipts and Processes" by Brannt. Book published by Henry Carey Baird and Company, Inc., 5 West 45th Street, New York, New York.

(b) Soft soldering

"Soft Solders and Their Application" by G. O. Hiers. Article published in "Metals and Alloys" 2, No. 5, 257, November 1931. This article contains an extended list of papers on the subject.

"Tin Solders: A Modern Study of the Properties of Tin Solders and Soldered Joints" by J. S. Nightingale. Book published by the British Non-Ferrous Metals Research Association, London.

"Substitute Solders" by F. N. Rhines and W. A. Anderson. Article published in Metals and Alloys 14, No. 5, 704, November 1941.

"Strength of Soft Soldered Joints in Copper Tubing" by A. R. Maupin and W. H. Swanger. Report BMS-58, National Bureau of Standards, 1940 (10¢).

"Strength of Sleeve Joints in Copper Tubing made with Lead-Base Solders" by A. R. Maupin and W. H. Swanger. Report BMS-83, National Bureau of Standards, 1942 (10¢).

"Physical Properties of Soft Solders and the Strength of Soldered Joints" by B. W. Gonser and C. M. Heath. Article published in Transactions, American Institute of Mining and Metallurgical Engineers 122, 349-371 (1936).

(c) Silver solders

"Silver Solders and Their Use" by R. H. Leach. Article published in Metals and Alloys 2, No. 5, 278, November 1931.

"Silver Solders" by R. H. Leach. Paper published in Proceedings of the American Society for Testing Materials 30, 493 (1930).

"Silver Brazing Alloys (Silver Solders)" from "Welding Handbook", 1942 edition, pages 571-586. Published by American Welding Society, 33 West 39th Street, New York, New York.

(d) Aluminum solders

"The Aluminum Industry", a two volume work by Edwards, Frary and Jeffries. Published by the McGraw-Hill Book Company, Inc., 330 West 42nd Street, New York, New York; contains several pages in Volume II on the soldering of aluminum.

The publications listed are usually available for consultation in the technical division of most large libraries. Books may be ordered directly from the publishers. A convenient method of obtaining copies of articles from technical journals is by means of photostat copies. Many libraries will undertake to supply such copies for a moderate fee. Two outstanding sources are Library of United Engineering Societies, 29 West 39th Street, New York, New York, and The Carnegie Library, Pittsburgh, Pennsylvania. U. S. Government publications listed above may be purchased for the price given from the Office of the Superintendent of Documents, Government Printing Office, Washington, D. C. (stamps not accepted).

X. Specifications

The Federal Specifications Executive Committee has issued specifications for the use of the departments and independent establishments of the government in the purchase of solders. Excerpts from these specifications giving the compositions of the various grades of each type are given below. The complete specifications can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C. for 5 cents a copy (postage stamps not accepted).

1. Specification No. QQ-S-551 for brazing solder (1932)

	Nominal Composition (percent)						
Grade	Copper	Tin	Lead, maximum	Iron, maximum	Aluminum, maximum	Zinc	Temperature of Melting, °F
A	49.0-52.0	none*	0.50	0.10	0.10	remainder	1600° (approx.)
B	49.0-52.0	3.0-4.0	.50	.10	---	"	
C	68.0-72.0	none*	.30	.10	---	"	1650 to 1760
D	78.0-82.0	none*	.20	.10	---	"	1725 to 1825

* As determined on a one-gram sample.

2. Specification No. QQ-S-561c for silver solder (1942)

	Nominal Composition (percent)			
Grade	Silver	Copper	Zinc	Impurities, Maximum
No. 0	19 - 21	44 - 46	33 - 37	0.15
1	44 - 46	29 - 31	23 - 27	.15
2	64 - 66	19 - 21	13 - 17	.15

3. Specification No. QQ-S-571a (1942)

Nominal Composition (Percent) and Melting Range of Lead-Tin Solders

Class	Tin plus Lead, Minimum	Tin	Antimony Maximum	Copper Maximum	Iron Maximum	Bismuth Max.	Zinc Max.	Aluminum Max.	Total Other(a) Elements Maximum	Approximate(b) Melting Range, °F Solidus	Liquidus
A	99.2	49-51	0.40	0.08	0.02	0.25	0.005	0.005	0.08	360	420
B	99.2	38-42	.40	.08	.02	.25	.005	.005	.08	360	460
D	97.6	34-36	.75-1.50(c)	.08	.02	.25	.005	.005	.50	360-365	490-500
E	98.[illegible]	28-32	.75	.15	.02	.25	.005	.005	.50	360	500-510
F	99.2	69-71	.40	.08	.02	.25	.005	.005	.08	360	378
G	98.3	18-22	.75	.15	.02	.25	.005	.005	.50	360	525-545
H	99.2	59-61	.40	.08	.02	.25	.005	.005	.08	360	372

(a) Analysis shall ordinarily be made only for lead, tin, and the other elements specifically mentioned in this table. If the presence of an excess of other elements is indicated in the course of routine analysis, further analysis shall be made to determine the total of these other elements.

(b) For informative purposes only.

(c) Minimum and maximum.

Notes: Class A is conventional half-and-half solder, used in "bit" soldering and for sweated joints in plain, tinned and galvanized steel stock and for copper and copper alloys.

Class B - same purpose as "A" but not so 'workable', also for dip soldering.

" D - customary plumber's wiping solder.

" E - used on automobile bodies for filling dents, etc.

" F - "Special-purpose" solder of high tin content, for soldering zinc, etc.

" G - automobile body work and for general purposes where a low tin content may be used also as a coating on steel.

" H - used in machine soldering of tin cans, also for soldering electrical connections where temperature limitations are important.

4. Specification No. E-QQ-S-571a, Emergency Alternate Federal Specification for Solder; Tin-Lead (August 1942)

Composition and Melting Range

Lead	Silver	Melting Range, °F Solidus	Liquidus
95.5 - 96.5	3.5 - 4.5	579	653